Time Efficient Assessment and Feedback Methods for Large Computer-Aided-Design Cohorts

TIME EFFICIENT ASSESSMENT AND FEEDBACK METHODS FOR LARGE COMPUTER-AIDED-DESIGN COHORTS

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ABSTRACT

Timely and individualized feedback on coursework is desirable from a student perspective as it facilitates formative development and encourages reflective learning practice. Faculty however are faced with a significant and potentially time consuming challenge when teaching larger cohorts if they are to provide feedback which is timely, individualized and detailed. Additionally, for subjects which assess non-traditional submissions, such as Computer-Aided-Design (CAD), the methods for assessment and feedback tend not to be so well developed or optimized. Issues can also arise over the consistency of the feedback provided. Evaluations of Computer-Assisted feedback in other disciplines (Denton et al, 2008), (Croft et al, 2001) have shown students prefer this method of feedback to traditional "red pen" marking and also that such methods can be more time efficient for faculty.
Herein, approaches are described which make use of technology and additional software tools to speed up, simplify and automate assessment and the provision of feedback for large cohorts of first and second year engineering students studying modules where CAD files are submitted electronically. A range of automated methods are described and compared with more "manual" approaches. Specifically one method uses an application programming interface (API) to interrogate SolidWorks models and extract information into an Excel spreadsheet, which is then used to automatically send feedback emails. Another method describes the use of audio recordings made during model interrogation which reduces the amount of time while increasing the level of detail provided as feedback.
Limitations found with these methods and problems encountered are discussed along with a quantified assessment of time saving efficiencies made.

KEYWORDS

CAD, assessment, feedback, computer-assisted, automated, audio, Standards: 8, 11

INTRODUCTION

The School of Mechanical and Aerospace Engineering at Queen's University Belfast has seen a significant increase in its student intake with numbers of new entrants almost doubling in 5 years; from 137 in 2008 to 247 in 2013. The increase in intake numbers has largely been as a result of increased international student enrolments and an increased quota within the university brought about due to greater demand for STEM (Science, Technology, Engineering and Math) subjects across the university. Additionally the School has experienced improved retention rates which in part have been attributed to better student engagement since the School adopted CDIO principles in 2003 and this has resulted in a further increase to cohort sizes beyond first year. All students in the School study an introductory CAD class in first year and the majority study an engineering design class with a significant CAD element in second year. The School currently has approximately 1000 students and 40 academic staff (faculty) giving a student:staff ratio of 25:1. The first and second year classes discussed in this paper are coordinated by individual academics, assisted by several research students who act as demonstrators in practical computer based laboratory sessions. Assessment in each case is done by a single academic faculty member.

Prior to the introduction of CAD to the curriculum, and in the days of small numbers of students producing designs at a drawing board, the marking of students' work was not particularly arduous. A significant part of their work often culminated in a single sheet of A1 paper for each student that could be ranked relative to their peers by sorting the classes work by a fairly superficial assessment of quality. Perhaps coincidentally, poor work was often quite grubby and dog-eared. A more detailed review would then take place by reviewing each piece of work in the previously ranked order and inscribing them with comments before applying a final mark. The first 2D CAD systems were little more than electronic drawing boards and the drawings produced by these systems could be treated in a similar way, but the introduction of Solid Models which only existed in the virtual form posed new problems regarding effective and efficient assessment.

RELEVANT LITERATURE

Computer Aided Design (CAD) is a relatively new addition to the engineering curriculum of degree programs when compared to the mathematics and engineering science courses typically found in the first and second years. There is little literature of particular relevance to the automated assessment and feedback of CAD, but there are a number of studies in other disciplines which have addressed many of the same issues faced by the authors of this paper.

In a study of automated approaches used for computer science programming assessment (Ala-Mutka, 2005) it was found that speed, consistency and objectivity of assessment can be improved, enhancing both student experience and learning. It was noted however that not all aspects of the assessment are necessarily suitable for automation and the identification and implementation of such an approach is likely best implemented by faculty with appropriate computing skills, such as those involved in computer programming instruction. The study also implied that there is a danger that assessment models might be developed based on what is convenient to automate rather that what makes best educational sense, or meets the stated learning outcomes of the course. Other potential pitfalls identified in this study included students seeking to cheat the automated systems after becoming familiar with how they operated. Overall the survey found that semi-automatic approaches enabled time to be spent on aspects of the assessment that necessarily require a more subtle interpretation and are more effectively carried out by human inspection.

Croft et al (2001) found that computer assisted assessment with automated feedback was an effective method for encouraging students to work harder at developing mathematical skills and that students tended to prefer this approach, not least because of the timely feedback it provided. Denton et al (2008) similarly found a favorable response from pharmacy students who reported automated electronic feedback as preferable to others in their cohort who had received a more traditional "red pen" feedback on a technical report. Students found the electronic feedback easier to read and the faculty took less time to produce this type of feedback.

Søndergaard and Thomas (2004) found that student satisfaction tended to fall as class size increased across their university (Melbourne) but that there were some large classes where student ratings of feedback remained unexpectedly high. Further examination revealed one such first year mathematics class achieved this through frequent summative assessment tasks combined with prompt (within 1 week) feedback which was generated using clear marking guidelines and a team of assessors drilled in the consistent application of the marking rubric.

Freney and Wood (2006) describe a prototype Computer Assisted Assessment (CAA) system designed for use across different disciplines which sets out to enable teachers to provide consistent, detailed and easily understood feedback in an efficient and timely manner. Clear assessment criteria and a menu of descriptors enable assessors to quickly provide consistent feedback by selecting appropriate tick boxes.

ASSESSING CAD MODELS

Semi-Automated Assessment and Feedback of a First Year Class

The introductory design course in first year is intended to give students an overview of engineering design, allow them to understand the importance of CAD in the modern engineering design environment, and allow them the opportunity to gain skills in using a modern 3D CAD package (SolidWorks). It is the starting point for them to develop skills which will be beneficial for design courses later in their degree, and in their engineering careers, and does not assume any prerequisite knowledge in this area.

The semi-automated assessment and feedback methodology described herein was born out of a number of research projects where the investigators were searching for information about the features in a CAD model. For example, in one project the feature parameter values and CAD measurement tools were used for optimization of a model for manufacturing applications (Zubairi et al, 2014). During this research an approach was employed where the Application Programming Interface (API) to the CAD modelling package was used to retrieve data for each feature in the CAD model. It was identified that this same process could be used to search for much of the information that the lecturer was having to discover manually during the assessment of a CAD model. The API to most CAD modelling packages gives the user access to an array of data related to the CAD model. Examples include the information in the feature tree (e.g. features, parameter values or settings associated with a feature), or information that can be measured by the CAD modeler, for example the volume of a model, whether or not the features in the sketches are fully defined, or the number of interference sites in an assembly. The creation of a fully defined sketch as the basis of a robust 3D parametric model is considered a fundamental skill and key learning outcome of this introductory course. The examination of such is a repetitive and time consuming task however which if done manually requires numerous menu selections and mouse clicks. In a similar manner to the work described by Ala-Mutka (2005) it was the expertise of the instructor that enabled the potential for automated assessment to be identified in the first instance and then effectively implemented.

An approach is described for the semi-automated assessment of computer aided design models. The semi refers to the fact that it is often still desirable for the lecturer to "eyeball" (manually interrogate) the submission during the assessment, and in the course of this work it was deemed preferable to assign some of the marks for each assessment manually. Again this approach is consistent with the findings of Ala-Mutka (2005).

The first step in the process is the collection of models from the students for assessment. For the process described students were required to upload their submissions to a university SharePoint site, which time stamped their upload. The lecturer was then able to download the students' submissions from the SharePoint site, which is an integral part of the university Virtual Learning Environment (VLE). During downloading of the submissions each of the files was automatically renamed, to include the student's name and student number appended to the beginning of the uploaded file name.

The assignment marks were recorded on a Microsoft Excel worksheet where a row was made for each submission, and the columns represented an assessed element. A Visual Basic for Applications (VBA) script which used both the Excel and SolidWorks API, progressed through each submission downloaded from the SharePoint site in turn. The script extracted the student name and number from the file name, and added this detail to a row in Excel where the marks for the assessment were to be recorded. The submission file was then loaded into the CAD system. This process significantly reduced the assessment time. The repeated operation of locating a file in the file system, creating entries in a new row in excel, and opening the file required significant time for large cohorts, and was considered a non-value added task. A conservative estimate of the time taken to complete these tasks manually is 20 seconds per student whereas the automated process carried out the same processes extremely quickly (~1 sec). For a cohort exceeding 200 students the time saving is in excess of 1 hour. It also overcame the problem that quite often when assessment was being carried out manually some submissions were missed on the way through the file system. Although this error was easily identified at the end of the marking process, as the number of marks and number of submissions did not equate, identifying which submissions had been missed was time consuming.

Once the submission was loaded into the CAD system, the script was also used to assess the submission. As stated above, the script can be used to determine a wide range of information about a CAD model. An important aspect if this approach is to be able to align the information which can be retrieved about a feature with the learning outcomes which are being assessed. For example, in the introductory CAD course one of the key learning outcomes is that students learn to "fully-define" all of the 2D sketches used in their CAD models as the basis of 3D features, as this is an example of good modelling practice. A script was written to progress through the CAD model feature tree, count all of the sketches in the model, and count how many of these were fully defined. Whether or not a sketch is fully defined with appropriate geometric constraints and dimensions is a specific property of the sketch that can be identified through the API. The count of the defined sketches relative to the number of sketches allowed a mark to be awarded for this learning outcome. The mark was placed automatically into the appropriate column in the Excel worksheet for that aspect of learning, and the row representing the work being assessed. Another example application for such a script is that if a student is provided with a series of steps (modelling features) they are to use to create a CAD model, then a script can traverse the feature tree and identify if all of these steps have been followed and the sequence in which they have been done.

Once all of the assessments have been marked, an Excel Worksheet is populated with marks against the different submissions for each of the assessed elements. This lends itself to the ability to deliver feedback to the students automatically. This is achieved using a VBA script which composes an individual message to each student, made up with comments about the quality of their submission, and potential routes to improvement, based on the marks recorded against each assessed element. For the example of checking for defined sketches, if it is recorded that a student has submitted a model containing nine sketches, only three of which were fully defined, the script could enter a line into the feedback stating:

> “Your CAD model consisted of nine sketches, only three of which were fully defined. Please review this topic using the notes from lecture 2, or by consulting pages 31-35 of the course textbook”.

When a complete message for the assignment was composed, it was automatically emailed to the student using the Microsoft Outlook API. The student’s email address was determined automatically using a lookup of their student identification number against the class email list.

One of the difficult aspects with assessing CAD is that it is at its heart a creative process. This means it is not always clear what information the script should be searching for in the feature tree in order to award a mark. For example, if a student is asked to model something as simple as a straight, cylindrical tube with constant wall thickness, there are number of different approaches which can be used. For example: to create an extruded boss from a sketch consisting of two concentric circles (Figure 1a), or to create a revolved boss of a sketch of the cross section of the tube (Figure 1b), or to create the extruded boss as a cylinder and insert the hollow as an extruded cut (Figure 1C) or revolved cut, or a hole feature.

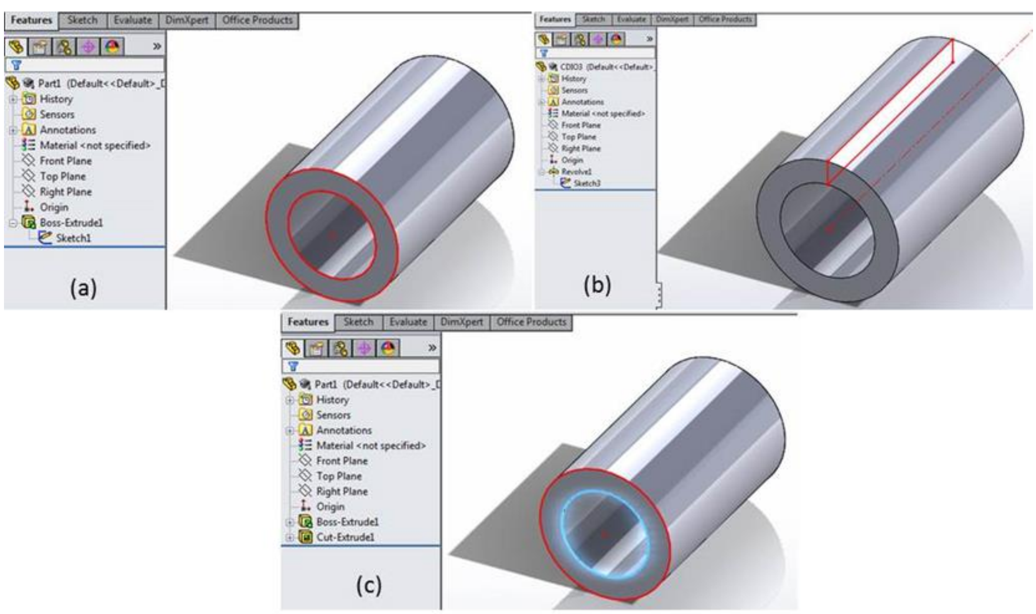

Figure 1 – Different methods of modelling a simple tube component

The diversity of valid modelling approaches therefore highlights some of the limitations which prevent fully automated assessment. The interpretation of modelling approach requires a more subtle interpretation than cannot be easily coded into a rule based algorithm.

Marking Solid Models Created by Second Year Students Using Excel Forms and Audio Files

For the last few years, the second year design assignment has been to produce a detailed design of a two stage gearbox. Each student has an individual design specification that has been made discrete by using various combinations of input shaft speed, power capacity and gear ratio. Figure 2 illustrates a sample of designs produced by students in one year, each produced to meet its own unique design specification. The learning outcomes for this second year class are different to the first year introductory module described above, which focused on the development of skills related to the use of parametric 3D software. In this instance one of the key learning outcomes is to use the software to develop a design which meets a product design specification and forms the basis for manufacture of actual parts.

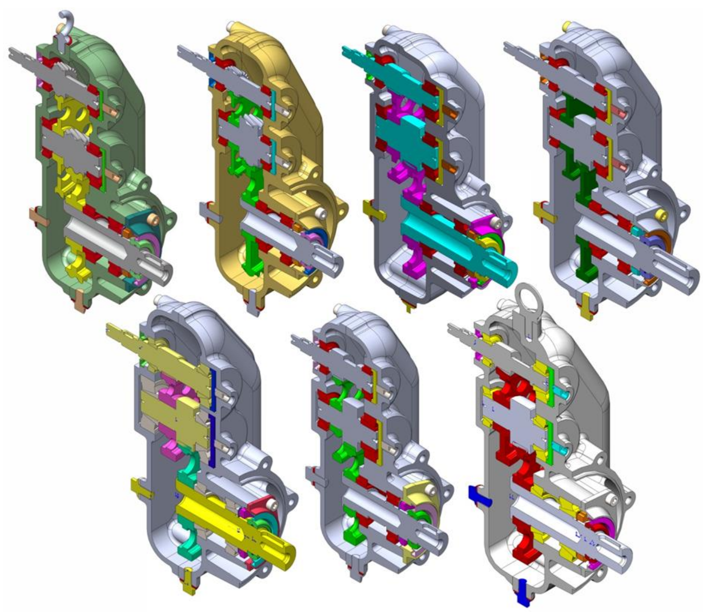

Figure 2: Student work – Gearboxes produced to seven different design specifications

50% of the final mark is based on the solid model. The rest is based on spreadsheets the students create to analyze the design and size components, a final report and a detail drawing of one side of the gear casing.

Verification that the design detail calculated has been correctly implemented is done by interrogating the CAD model. The first class to undertake the project comprised 85 students and it was clear from the onset that marking the solid models would take several days. A subjective approach to the marking was ruled out as it is difficult to be consistent over a long period of time and for the mark to be defendable some tangible justification for the mark is necessary. Instead, the approach used was to look for faults in the design and write these down in an abbreviated format on a form. Various categories of fault were used with higher penalties applied to faults in the first two categories in the following list:

- ***Practical to Manufacture / Possible to Assemble:*** Reverse draft, Square end key slot, One part fused into another (see also relationships). Smaller errors are parts that are difficult rather than impossible: Thin sections or gaps.
- ***All Features:*** Gross omissions such as part of the gear case. Missing feature that causes design failure, i.e. missing shoulders for bearings to butt against, no oil filler/drain, no bearing adjustment, missing seals. If drive hubs were assembled to the

input and output shafts are there shoulders to butt against that are outside of the gear case outline. Smaller errors are for partial omission: shoulders that are too small, adjusters that are too thin.

- **All parts fit:** Do the bearings fit their bores and shafts? Is there adequate clearance for the gears? (note if ref diameter has been used for the gears this will be considered as an error), Do other parts rub together that should not? Is there a general failure caused by moving of a grounded part (use interference check)? Note: For simple interference or alignment errors apply penalty once only for any one shaft.

Smaller penalties were also applied for failed part features, missing or failed assembly relationships, incorrectly sized standard parts and missing corner radii chamfers or casting draft omissions.

To open a student's solid model, manipulate it, view it using the dynamic section tool to identify faults and then record everything on a form and tally the faults score would typically take 15-20 minutes. Good models were quicker and really bad ones could take nearly 30 minutes. It was found that being as strict as possible in the interpretation of what constituted a fault gave the most consistent fault scores. This was tested by remarking some samples of work a week later.
The higher the faults score obtained the lower the quality of the work. A non-linear conversion table was derived to change the faults score into marks based on a subjective review of models with various faults scores. To mark the entire first class of 85 took a little over 25 hours spread over 3 days. Filling in the score sheets was tedious and interpreting the abbreviated notation would be difficult for anyone other than the author. The problem was compounded in subsequent years by a steadily increasing class size; the current class size (2014/15) is 175 students. An alternative more time efficient approach was required!

Since 2012/13 the following approach has been used. In a similar manner to the approached described by Freney and Wood (2006) a form was created in an Excel workbook that allowed the scoring to be completed by clicking on various buttons; the form is shown in Figure 3. Buttons at the top of the form allow scrolling through the student names with the various areas of the gearbox being inspected and faults being recorded in the appropriate row. These are generally classified as gross faults or minor faults. The weighting for each fault type is specified by a column in the spreadsheet that records the number of faults against each student and fault heading. It is not possible to scroll to another student without loading the fault counts from the form into the spreadsheet or alternatively resetting the form to the fault counts previously logged in the spreadsheet.

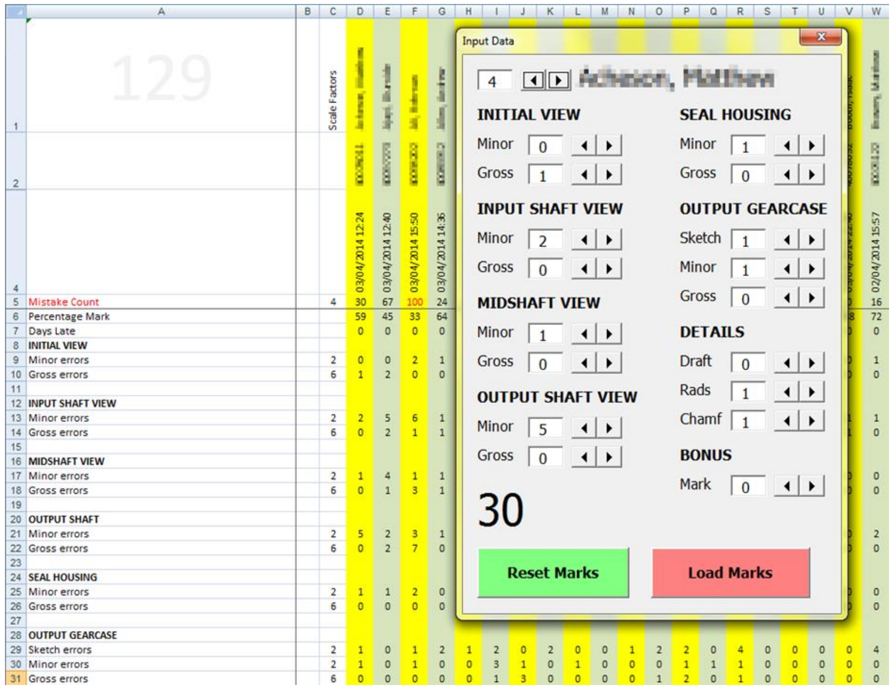

Figure 3: Form used to enter model fault count into a spreadsheet

By themselves, the fault counts would be difficult to defend as they don't specifically identify the reason for each penalty. This needs to be noted separately. As writing the justification out had proved tedious and time consuming an easier and quicker approach was sought. This was provided by recording an audio commentary as each model was reviewed. Video recording was considered using Camtasia but was dismissed due to the large file size created and the additional video component was considered unnecessary as it added little to the student's understanding of the feedback.

In the audio commentary the area of the model being looked at would be identified and the fault would be noted along with its type (gross or minor). The audio was recorded using the sound recorder option under the accessories provided with a standard MS Windows installation. Initially a SAMSON C01U USB studio condenser microphone was used but this proved to have quite a lot of background hum and it was difficult to maintain a consistent sound level as it was a desktop microphone and it was necessary to keep a constant distance from the microphone and resist head turning movements. This was replaced by an AKG C520 head mounted condenser microphone connected to the computers USB port via a Focusrite Scarlet 2i2 audio interface. This is a more expensive solution but has proved to eliminate noticeable hum and provide very consistent recordings.

The assessment of the students was performed on two separate but adjacent computers. The solid model was reviewed on one computer and the assessment workbook was on the other. The audio files were recorded on the same computer as the solid models and this also had an open spreadsheet with the students name and ID listed which could be copied and pasted into the sound recorder when the file was saved.

The saving in assessment time was dramatic. It was now possible to mark 8 -12 students per hour. Typically the audio commentary would be 3-5 minutes in duration. The rest of the time was opening or closing the solid model file and orientating and sectioning the model.

Although the creation of the audio files was primarily developed to speed the marking process its usefulness to provide formative feedback to students has also been experimented with.

Throughout the year leading up to the final assessment students attend practical classes where they develop their solid models and are provided with formative feedback from the instructor and a number of postgraduate demonstrators. It is difficult to ensure that all students receive the same quantity and quality of feedback or to spend equal time, or even sufficient time, with all students in a large class. This is especially true as some students are very demanding while others are less inclined to ask questions. To address this, audio feedback on each and every student's work was offered to the class approximately half way through the year. There were no marks associated with this interim submission, the feedback being entirely formative. A significant portion of the class however elected not to submit their work, perhaps due to embarrassment at their lack of progress.

In 2013/14 only half of the class submitted their models for formative feedback. Comparing the end of year marks for student models between those that were provided with formative feedback and those that were not, revealed that the average mark obtained by the former group was 10% higher than those who had not received the formative feedback. Clearly students that did not submit their work for feedback are less engaged than those that did. It would therefore be wrong to conclude on the basis of this basic analysis alone that the higher average was a direct consequence of the feedback. However, of those that did submit their work for feedback there was a consensuses that the feedback was useful and only a very few students had difficulty understanding what was being said. The low percentage of the class choosing to request formative feedback was both surprising and disappointing, particularly since in the annual National Student Survey (NSS) students in the School have consistently expressed least satisfaction in the areas of assessment and feedback.

Now that such feedback can be more efficiently and effectively provided the next challenge will be to engage more of the students in this aspect of their learning.

DISCUSSION

In an assessment regime where there are many summative assessment elements such as assignments and class tests during the academic year it may be that students are less inclined to engage with formative assessment elements. This might occur if they are strategically trying to accumulate marks towards their final degree classification, or simply gain enough credits to proceed to the next year. The observation of the authors is that the better students are more likely to engage in formative assessment elements but that the weaker ones, who potentially might gain the most, are less likely to engage. It may be that better uptake of formative assessment requires a curriculum or program level approach rather than small changes within a module.

CDIO standard 8 (Active Learning) is an integral element of how the modules described herein are delivered. Students are challenged to develop design skills through the use of software tools in an environment where they are supported by lecturing staff and teaching assistants. In a large computer facility it is often those that shout loudest who are heard and subsequently helped most by the scarce number of demonstrators. The methods described have an additional benefit of providing guidance and feedback which can be accessed multiple times and outside class time for those that don't either understand immediately or are reluctant to speak up in the first instance. In this respect such methods as part of a blended learning environment are more inclusive.

Although not described here, the recording of assessment in a spreadsheet format also facilitates the analysis of common errors made by students. This data can then be used as part of the module review process to improve content delivery in future years.

The methods for semi-automated assessment described herein utilized the already established skillsets of several faculty members as an effective means of improving assessment efficiency. It is perhaps unlikely that the same needs and skillsets are replicated at other institutions and as such what is described here is not a recipe that might be copied exactly elsewhere. The literature review however highlighted that the approach adopted was consistent with the work of others in different disciplines and that an audit of needs and capabilities in other contexts would form a necessary first step if similar efficiency gains are to be realised.

CONCLUSIONS

- A number of CAA and automated feedback approaches implemented in other disciplines were found to be analogous to the requirements of the assessment of CAD models.
- The semi-automated approaches developed for assessment of CAD submissions have significantly reduced the amount of faculty time required to carry out the assessment of large cohorts.
- As a consequence of the improved efficiency of the assessment, a more consistently high quality and more timely formative feedback has also been made possible.

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